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**Critical Literature Review
(ANTA602)**

Astronomy in Antarctica, current projects, future goals and challenges

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Abstract (ca. 200 words):

If you were to ask an astronomer to define the perfect place to locate a telescope, they'd tell you to have it somewhere cold, dark, at high-altitude, with a local climate that contained dry stable air. In short, Antarctica.

In New Zealand for example adverse effects, such as the movement air in our atmosphere, can cause images to wiggle and warp, such as the observable twinkling of a star in the night sky. Antarctic astronomy, including the operation of the South Pole Telescope, located at Amundsen Station, can largely overcome these problems. In taking advantage of the cold dark skies, these telescopes are able to probe the deep reaches of space, in order to answer some of the fundamental questions related to the universe, including the search for theoretical dark matter and dark energy. Other less conventional astronomy related projects in Antarctica include the 'Ice Cube array'. This uses ultra-sensitive light detectors, buried over a mile deep in the Antarctic ice sheet, to detect high-energy neutrinos that were created by the most violent events in the universe, which allow astronomers to visualize distant cosmic events by detecting the neutrinos they create. Other scoping studies have identified several high altitude sites in East Antarctica such as those at Dome A and 'Dome C' where there is the potential to locate a very large optical or Infra-Red telescope for the search of

earth-like planets in other solar systems. Housing such complex equipment in these remote areas, as well as keeping the stations supplied and maintained, is not a simple task and this review will examine the science produced, technical challenges that have to be overcome, potential environmental impacts, as well as examining whether the science produced is worth the costs and resources involved.

Space Research in Antarctica, current projects, future goals and challenges



South Pole Telescope, Antarctica, Source: www.space.com

Introduction

The Antarctic environment contains some of the most inhospitable conditions to life on this planet, but these unique conditions also make it an ideal place to study the night sky (Kaufman, 2014). The cold air contains very little water vapor, which results in less emission of infra-red light that would typically interfere with ground based observations at more northerly latitudes (Storey, 2009). In the winter the majority of Antarctica also experiences 24 hours of darkness, which allows for continuous observations of the night sky and thus minimizes daily air current oscillations. Due to this highly stable air column the 'twinkling' effect in stars that can often be observed at more northerly latitudes is therefore greatly reduced (VanCleave, 2010).

Antarctic Astronomy is a well-established discipline, with its origins centered over 100 years ago following the discovery of the Adélie Land Meteorite in 1912. Since that date more meteorites have been discovered on the continent of Antarctica than in the rest of the world put together, largely due to the snow and ice being a perfectly contrasting material to see these dark colored objects on (Burton, 2006). In addition, ancient meteorites that were buried within the ice can be carried back to the surface through the glacial processes of rising hard blue ice, and can accrue in considerable concentrations in areas such as against the flank of the TransAntarctic Mountains. Antarctica's other unique features include the continent's high geomagnetic latitude, which was first exploited in the 1950's for the measurement of cosmic rays at the Australian Mawson Base and from the US base at McMurdo.

Optical astronomy began at the South Pole in 1979 with a relatively small 8 cm optical telescope designed to measure solar oscillations (Grec et al., 1980). More modern telescopes now focus on producing very precise measurements of light in the infra-red (IR) and millimeter region of the spectrum. In taking advantage of the relatively low IR emissions, these telescopes, first set up in the 1990's, examined aspects such as the cosmic microwave background radiation and the origins of the universe (Carlstrom et al., 2009).

Regions such as the South Pole can however suffer from turbulent air due to the strong katabatic winds that predominate in these regions. Larger optical and infrared telescopes are therefore somewhat limited in their performance in this region and, as a result, no future large optical telescopes are planned for this area, primarily due to the costs involved and limited gains from being in such a location (Rathborne and Burton 2005).

In other areas of the continent however, the vertical air columns have shown to be more stable, with the potential to utilize this stability to site an optical telescope. Preliminary studies in 2003-2005 at Concordia Station, which is referred to as 'Dome C' on the Antarctic Plateau, indicated this area may be a potential candidate for such an observatory. The thick atmospheric boundary layer, which prohibited effective optical measurements being taken at the South Pole, was shown to be significantly thinner at this location and consequently produced a much lower IR background level (Von Walden 2003; Carlstrom, 2003). More recent investigation of this area has however cast doubt over several of the initial measurements reported (Abdelkrim et al., 2005) and further research has now moved to another potential site identified by American and Australian scientists known as Ridge A.

In essence, the main advantage to Antarctic astronomy is that the continent can offer a number of unique conditions and environments that are conducive to maximizing the potential of certain experiments and observations. The 'Icecube' array for example, which commenced operations in 2005, uses optical sensors buried between 1450 and 2450 m into the ice to detect minute flashes of light generated by high-energy cosmic rays (Halzen 2004). Other 'neutrino telescopes' have traditionally relied on burying the detector medium underground, although having a large volume of ultra-pure deuterated water underground can create a number of safety and logistical issues, as well as possessing only limited spatial sensitivity from using such a relatively small detection device. Other small-scale detector arrays have been placed in the ocean, however in order to maximize the chances of detecting a neutron event it is advantageous to construct the largest detector possible, and this is only realistically feasible using Antarctic ice. The 'Icecube' experiment demonstrates that, through examination of a unique environmental condition, scientists are able to use this to their advantage in devising experiments that would otherwise be difficult, or impossible, to recreate elsewhere (Sample, 2011).

Comparisons between current Antarctic Astronomy and its alternatives

In optical and IR astronomy, the construction of telescopes in Antarctica may be perceived as expensive; however, these costs are considerably less when compared to the cost of launching a satellite of equivalent capability into space. At present, 1 kg of cargo costs approximately NZ \$12 to ship to Antarctica (Post Office, 2015) with subsequent internal shipping costs which may vary. In contrast, the deployment of 1 kg of material into a low-earth orbit can be expected to cost approximately US\$10,000 (NASA, 2015). Site conditions in Antarctica, such as no dust, stable direction wind, and clear skies also greatly reduce the telescope costs, as smaller equipment can be used to give equivalent results to a much larger device located at more northerly latitudes (Ashley. M., Burton. M and Storey. J. 2004). Conversely, logistics and shipping costs can undergo a significant reduction if the device, or experiment, is housed near one of the many current astronomical observatories, such as those in Hawaii, Chile, or certain parts of Europe and New Zealand.

This review illustrates some of the current and future initiatives that have been deemed appropriate and cost effective for their location in Antarctica.

Optical and IR Astronomy

Interest in Antarctica as a site for optical space observatories has accelerated since 2004 when the University of New South Wales (UNSW) astronomers published a paper in the journal *Nature* confirming that a ground-based telescope at Dome C would be able to take images of equivalent quality to those produced by the space-based Hubble telescope (Lawrence et al., 2004).

An Anglo-Australian team completed the first detailed study into the practical problems of building and running the proposed optical/infra-red PILOT telescope project in Antarctica. The proposed 2.5-metre telescope would have had an estimated cost in excess of AUD \$10million (Storey, 2009). In order to resupply the current facilities at Concordia Station an ice-breaker currently sails between Hobart and the French coastal station of Dumont d'Urville, with subsequent haulage using tractor trains across 1200 km to the base. Each traverse takes approximately 11 days and carries 150 tons of supplies, with up to three such traverses are made per year (Ashley et al., 2005; Storey, 2009). Logistically this initiative is currently not without its challenges, which would only be magnified should the telescope and associated infrastructure be built at this site. In addition, special measures are required to allow a telescope to operate reliably in a cold environment, and this station, typical of many others in Antarctica, is effectively cut off from the rest of the world for at least 6 months of the year. As well as the logistical complications in siting an optical telescope in Antarctica, there are also some astronomical limitations, as less of the sky is visible from Antarctica than at sites closer to the equator. Aurora and less dark time, where the sun is well below the horizon, can also hinder observations (Riffenburg, 2009). Despite these challenges it has been estimated that a telescope with a 4m aperture mirror would be capable of producing an optical image with a resolution similar to that of the Hubble Space Telescope for approximately 10 percent of its observations. This value increases fivefold if the image is observed in Infra-Red, which carries certain advantages in being able to resolve clouds of gas and dust not discernable in the visible spectrum. Future feasibility studies have therefore centered on the possibility of using this form of astronomy as the most suitable for Antarctica.

Following on from Dome C, a joint US-Australian research team combined information from satellites, ground stations and climate models in a study to assess the variety of factors that affect astronomy - cloud cover, temperature, sky-brightness, water vapor, wind speeds and atmospheric turbulence (Travouillon et al., 2003).

The researchers isolated a location, designated as 'Ridge A', 4,053m above sea level on the Antarctic Plateau. This site is extremely cold and dry, with astronomical images taken at Ridge A predicted to be at least three times sharper than at the best sites currently used by astronomers (Gafney, 2009). As the sky there is considerably darker and drier, it means that a modestly-sized telescope there would be as powerful as the largest telescopes anywhere else on earth.

One of the reasons an optical space telescope provides such a clear image through a relatively small mirror is due to the lack of an atmosphere, which on earth can cause distortions to light gathered by the device. Modern observatories have improved their seeing conditions with hardware called adaptive, or active, optics (Crépy, B, 2009; ESO, 2015). This system employs lasers, or star images as a reference to compensate for the atmosphere's distorting effects, then actuators on the underside of the mirror flex the telescope's surface by minute quantities to partially compensate for the distortion detected. There is a limit to this technology, but if the distortion is relatively minor without correction, using adaptive optics can therefore produce high quality images to rival any current land or earth orbiting observatories (ESOa, 2015).

Optical Antarctic telescopes, in essence, provide a 'halfway house' between the extremely expensive space telescopes and large terrestrial based observatories housed in more accessible locations, such as Chile or Hawaii. In contrast, at present, there are a number of very large ground-based telescopes being built, such as the Giant Magellan Telescope (GMT) or the European Extremely Large Array, both scheduled for completion within the next ten years (GMTO, 2015, ESOB, 2015). These telescopes have a segmented primary mirror with an expected resolving power 10 times greater than the Hubble Space Telescope and will be the largest optical observatories in the world. With costs close to \$1 billion and involving multiagency/country funding, Chile has been chosen as the host country for these telescopes. Their price tag is significantly higher than that of the proposed telescopes at Dome C or Ridge A, but the Chilean site will be able to be manned full-time and permit relatively easy access, as opposed to those sites identified in Antarctica, which are likely to suffer from issues around maintenance, power supply and increased installation costs (Riffenburg, 2007). With improvements in the field of active optics it becomes less critical to have a very low distortion, as this can be somewhat corrected for using this system (ESOb, 2015).

Cosmic Rays and Neutrino research

The 'Icecube' research station started 2005, with a focus to identify high-energy neutrinos from deep space. These are particles which were created by events such as black hole formation, gamma ray bursts from dying stars, or the collapse of super massive stars to form supernovas. The detector array can identify these rare neutrino interactions within the surrounding ice through a network of ultrasensitive light detectors (Sample, 2011). In order to site these detectors in the ice a 'hot water' drill was employed to permanently sink the detector into the ice sheet where it would remain in situ. In creating this array the polar ice provides the perfect neutrino detector containing a large dark medium that is transparent and capable of interacting with some of the neutrinos that pass through it. (Icecube, 2015).

The Icecube experiment is the largest neutrino telescope in the world and has produced a number of scientific publications, with observations including a shadowing effect of these neutrinos from the

moon when aligned in front of the sun (Aartsen, et al., 2014). A number of high energy neutrinos have also been detected, possibly of astrophysical origin, making them the highest energy sub atomic particles discovered to date. Such information is currently aiding in the search for dark matter and the origins and processes that are required to create these very high energy low reactivity particles (Icecube 2015).

With a price tag close to US \$271 million, this is not however an insignificant amount of money, but in comparison to the optical telescope price tags discussed above, it is relatively inexpensive. By taking advantage of shielding and a medium to display the cosmic ray interactions provided by the ice, this has kept costs relatively low. Expensive external shielding or large volumes of chemicals housed in underground mines, as is typical with several other neutrino experiments, can largely be negated with similar results being produced.

Meteorites

Throughout the world there is a relatively even distribution of meteorites impact events, however these rocks can often be difficult to find as they are frequently indistinguishable from the surrounding bedrock material, or can quickly be hidden/weathered, or covered by vegetation (ANSMET, 2015).

The Antarctic therefore provides some unique locations to find meteorites, with no other sites in the world providing the same frequency of finds that occur in these regions (Stiles, 2005). The Antarctic Meteorite Program administered by America is a cooperative between the National Science Foundation, NASA and the Smithsonian Institution to collect, curate, document and store such specimens. With an impressive success rate in finding and identifying these extra-terrestrial objects the program continues to be a relatively inexpensive initiative that has provided numerous samples from the Moon, Mars, and previously un-sampled asteroids. Such rocks are pivotal to our understanding of the history of the Solar System and the potential origins of life on earth.

Collection points for these meteorites have been identified based on the known migration of ice flows in these regions. The base of the Transantarctic Mountains serve as a productive collection point for meteorites, which originally fell on high-altitude ice fields in the central plateau of East Antarctica. These meteorites rapidly become covered in snow and travel "downhill" across the Antarctic continent, while embedded in a vast sheet of flowing ice. The Transantarctic Mountains can act as a barrier to this flow and subsequent wind erosion of this stationary ice brings trapped meteorites back to the surface, where they may be collected.

The ice-flows therefore concentrate meteorites into a few specific areas providing significantly higher aggregations of these rocks than would be found anywhere else. Furthermore, the contrast of the dark meteorites against the white snow, and lack of terrestrial rocks on the ice, allows these specimens to be readily identifiable (Richter et al., 2011).

The potential science that could be gained from analyzing these meteorites was illustrated in 1996 when scientists at NASA controversially announced the identification of apparent fossilized bacteria in a Martian meteorite sample. Since then much of the evidence has been challenged and it is currently believed that the sample identified did not contain any previous evidence of primitive life from another world. This discovery does however demonstrate the potential importance of examining such rocks, as well as highlighting Antarctica as a unique area where meteorites can readily be found and the possible science that can be garnered from their discovery.

Discussion

Space astronomy offers a gold standard in terms of its ability and potential to examine the universe. Due to the costs involved in deploying and maintaining such satellites, their widespread use and accessibility has been somewhat limited (Storey, 2009). In addition, terrestrial-based telescopes at more northerly latitudes have significantly improved and overcome a number of limiting factors that once made space telescopes reign supreme (ESO, 2015). Antarctic astronomy could be envisaged as a discipline in between these two facilities, in possessing some unique environments to conduct research, but still presenting challenges regarding the equipment used and remoteness of the locations chosen.

In addition, the cold, dry nature of Antarctica has many analogies with the surface of Mars, and significant research has been undertaken in areas such as the Antarctic Dry Valleys in order to test equipment that could one day be deployed to an alien world. For example, NASA's current IceBite project has tested ice-penetrating drills for potential future missions to the Martian polar north in the Antarctic environment, as well as future missions to icy worlds such as Jupiter's giant moon Europa (Bortman, 2010).

Conclusions

Antarctic astronomy and space research have a long history of exploiting the unique environmental conditions and topography of this continent to gain an insight into areas of science that would be very difficult to replicate anywhere else on the planet. The key to this research is to try and use conditions and environments already present in Antarctica to one's advantage. Such research will continue to play a key role in future astronomy and space exploration, but, as with any location, there remains a number of drawbacks and technical challenges to be overcome.

High wind speeds and thick atmospheric boundary layers at most of the current Antarctic field stations prohibit the use of very large telescopes due to the limited gains in installing equipment in these areas, as opposed to more accessible sites in Chile, Hawaii or the Canary Islands. Sites identified for future optical astronomy are in very remote locations and would require substantial infrastructure to maintain their operation, as well as potential remote operation and the issues around maintenance and repair. For these reasons the majority of large optical telescopes are still proposed for the more accessible locations listed above. The current Hubble Space Telescope has largely been surpassed by improvements in ground based optics and its performance can be overshadowed by a number of current and planned ground based telescopes.

The future 'James Webb Space Telescope' will provide an opportunity to view the universe using systems and equipment that cannot be replicated on earth, even in Antarctica, so while this price tag is a lot higher than either Antarctic astronomy or the more standard ground-based telescopes around the world, the science it will generate will be unique and impossible to replicate anywhere else. Conversely, research such as hunting for meteorites, has proven to be very productive in Antarctica, and the 'IceCube' neutrino telescope array would be difficult to replicate anywhere else on the planet.

Antarctic astronomy provides some unique opportunities to further our understanding of the cosmos, and future challenges will arise in identifying such opportunities and how best to exploit them. As technology improves and potential warming of the continent allows greater access to remote locations, it may also become more cost effective to locate bigger optical telescopes in

Antarctica. This will depend on current advancements in space technology and that of other ground-based observatories. Antarctica still remains the best place on earth to see the night sky, and it is anticipated that the continent will continue to provide a wealth of astronomical data for many years to come.

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